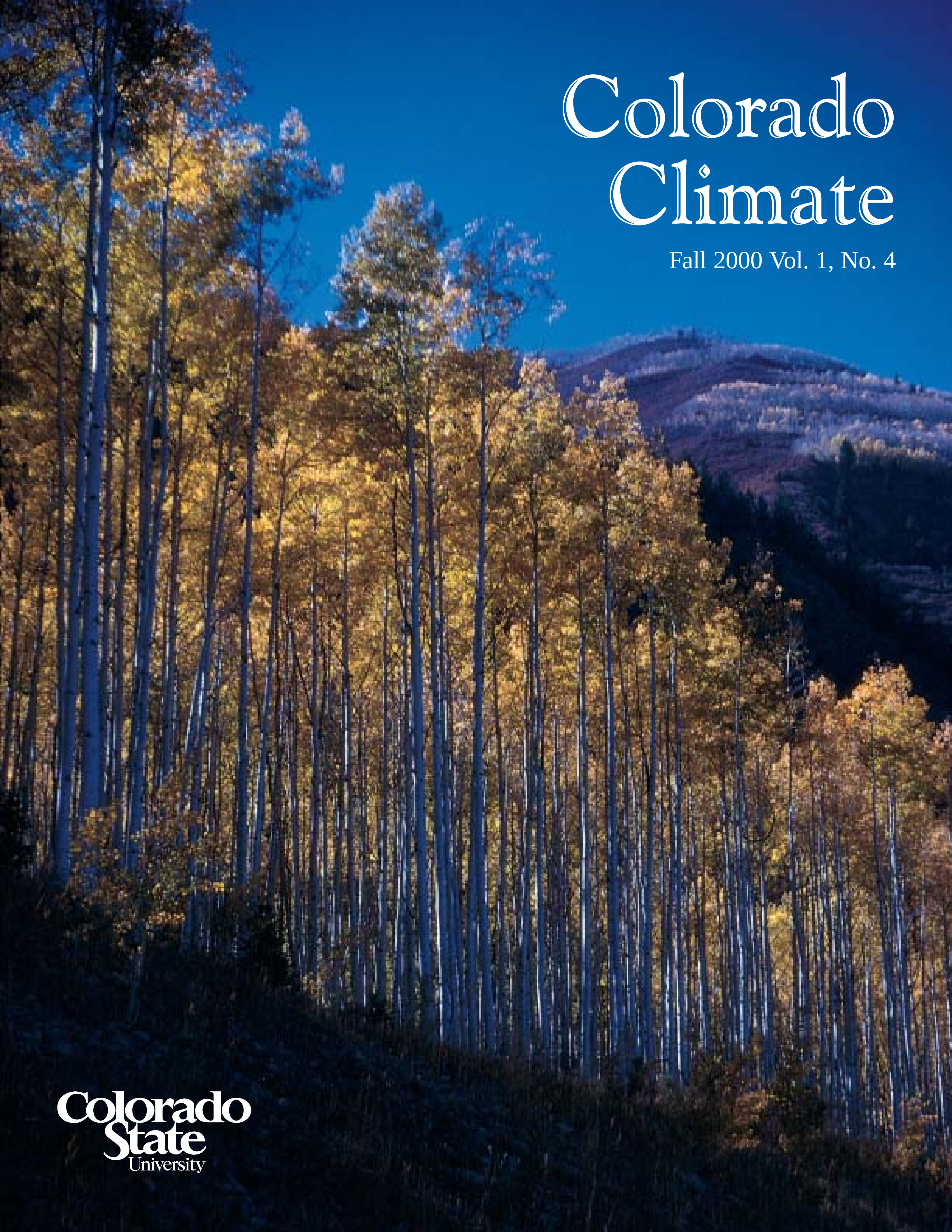
Colorado Climate

Fall 2000 Vol. 1, No. 4



Colorado State University

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Cover Photo: *Fall Aspen Trees in Southwestern Colorado. Photo by Nolan Doesken.*

If you have a photo that you would like considered for the cover of Colorado Climate, please submit it to the address at right. Enclose a note describing the contents and circumstances including location and date it was taken. Digital photographs can also be considered. Submit digital imagery via attached files to: odie@atmos.colostate.edu. Unless otherwise arranged in advanced, photos cannot be returned.

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Climate Memories – A Blizzard or Two Is Good for You

Nolan J. Doesken

Part of who I am and who you are comes from memories and past experiences, both good and bad. There is nothing like witnessing severe weather, be it a quaking thunderstorm, a sudden flood, or a howling blizzard, to make us just a little stronger, a little wiser, and perhaps a bit more humble.

I don't mean to say blizzards are good. Looking back at past blizzards in Colorado, dozens of people have lost their lives along with hundreds of thousands of livestock since European settlers made their way to the Great Plains and Rocky Mountains. Hunters, hikers, and skiers sometimes lose their way and occasionally die as blowing snow obscures friendly landmarks. As recently as 1997, several people died in the teeth of an October blizzard.

Last year, 1999, we missed an opportunity to commemorate one of the Great Plains' most memorable blizzards, "The Blizzard of '49," on its 50th anniversary. Thousands of people in northeast Colorado will still be happy to tell you what they remember from that incredible storm. It would be worth your while to listen to them, too. In Nebraska, that storm still ranks near the top of the list of most important news stories of the 20th Century. Books have been written and even a movie or two has been produced that captured and shared some of the intense life-or-death experiences of that early January storm.

Think about your own life. Can you think of a blizzard or awesome snow or ice storm that you still remember like it was yesterday? I recall one blizzard and two ice storms from my childhood in central Illinois. Ice storms aren't a big part of our climate in Colorado, but in the Midwest they were nature's tree (and powerline) pruners. After hours of steady rain falling from leaden clouds, and temperatures of about 28°F with gusty northeasterly winds (I paid attention to that even as a young child), trees began to bend, sway, and crack. One dared not venture outside no matter how great the urge. Each crack was like a gunshot. The lights flickered and then went out. School was cancelled for what seemed to be months (memories are neat, but not always accurate). For my sisters and I, it was a wonderful time – playing games, assembling puzzles, telling stories, playing piano, and singing together. When the sun came out two days later the landscape was unreal. Natural piles of jumbled tree branches under each large tree stretched much higher than my head. My path was blocked in all directions but the landscape was beautiful beyond words – glistening like a million diamonds delivered as a gift from heaven.

My parents' memories were a bit different. My father recalled sleepless nights as he worried about frozen pipes and fire hazards from lamps and candles. Every hour or two he had to shovel coal into the old furnace to keep us from freezing while we children joyfully but naively laughed and played. He remembered the creaks and groans that came from the roof, especially as the wind blew. The weight of several inches of ice was a burden that he was not sure the old house could bear. He remembered all the crews of men and their trucks working day and night to restore power. My mother remembered melting ice and snow so we could have water to drink and cook with. She remembered scrounging canned goods and relics from the bottom of the freezer to keep us all fed. Then, when the temperatures warmed a few days later but miles and miles of power lines and poles still laid on the ground, she remembered the big sale at the grocery store where all the meat from the "locker" was distributed before it spoiled. My parents are long gone from this life, but they took those memories with them to their final days. So will I.

1913 snowstorm. Photo courtesy of the Colorado Historical Society.

Not all memories need to be of childhood storms. The blizzard of October 1997 is still fresh in my mind and will be for a long time. I can't tell you the whole story now. We don't have enough space here. But I'll start.

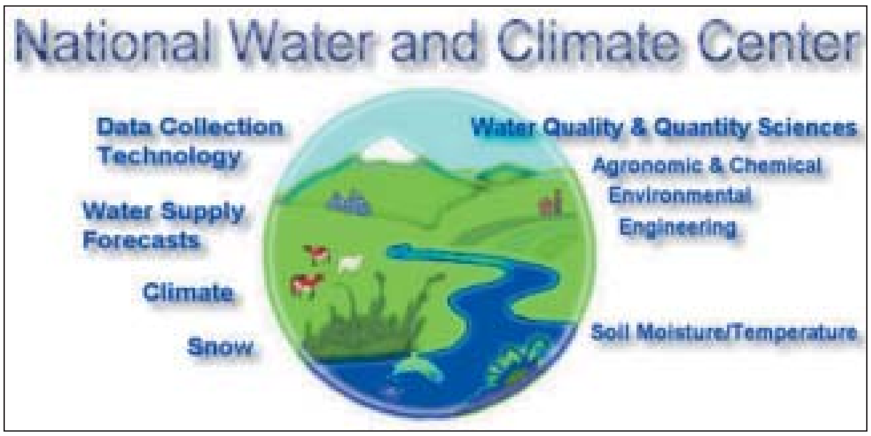
I have always been thrilled by winter storms, but I hate traveling in them. If at all possible, I pay close attention to weather forecasts and alter my plans if necessary so that I am safe at home before a big storm hits. Storms are fun when they can be watched and enjoyed from a safe and warm haven. Such was not the case that autumn night three years ago. My boss, Tom McKee, his wife, Lee, and I were returning to

(continued on page 4)

Climate on the Web – Natural Resources Conservation Service

Nolan J. Doesken

As the autumn months pass and winter sets in, this is a great time to practice checking out mountain snowpack levels and anticipated water supplies. The Natural Resources Conservation Service websites are great places to go.

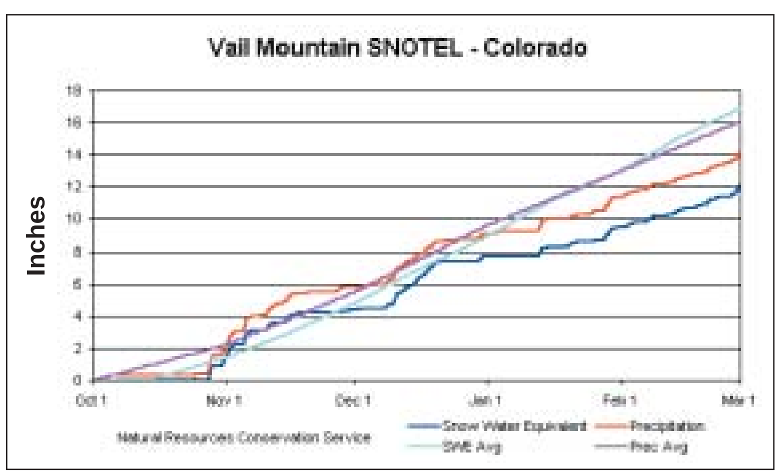


http://www.wcc.nrcs.usda.gov

http://www.co.nrcs.usda.gov

For many years, the measurements of snow depth and water content from Colorado's snowiest locations were undertaken by teams of snow experts equipped with special coring tubes and scales who would visit special "snow courses" once each month from late winter through spring. These adventurous folks took measurements on skis, snowshoes, or whatever it took to get them high into the snow accumulation zones of the Rockies. Each month, water planners with their eyes on the mountain snowpack would anxiously await the findings. Things have changed in the world of snow surveying in the past 20 years with the help of SNOTEL (SNOw TELemetry), an automated system for measuring snow water content and radioing the results automatically each day using "meteor burst" communications. Now each of us can track snowpack accumulations pretty much anywhere in the western states all year round from the friendly, warm comforts of our computer desks. Snow depths, water contents, comparisons with average conditions, historical analysis, and predictions of summer water supplies are just some of the information you will find. There are countless maps, graphs, and tables of information, many of them right up to this morning's reports. Quite frankly, it's amazing. And if snow isn't your passion, you can also track reservoir levels and even soil moisture at sites across the country. Summaries of climate information for every county in the country can also be selected. If you're not careful, you could spend the whole day at this site, so be ready.

My guess is if you love snow, and are interested in the mountains, you'll be visiting this site a lot from now on.



Daily precipitation (——) and snow pillow measurements of Snow Water Equivalent (——) compared to average (——) and (——) for the NRCS Vail Mountain SNOTEL.

A Time for Time Series – Trends in Observed Solar Energy in Colorado

Nolan Doesken

Last issue we showed you long-term trends and variations in the number of clear and cloudy days observed at a few Colorado weather stations. From the 1950s into the 1980s, the number of cloudy days increased significantly. More recently, that trend seemed to be leveling out. However, a change in observing procedures and instrumentation during the 1990s at airport weather stations interrupted that time series.

The creation of COAGMET (Colorado Agricultural Meteorology Network) in Colorado about a decade ago inadvertently helped bridge this chasm. Each of the agricultural weather stations included a low cost electronic sensor for estimating solar energy reaching a horizontal surface at ground level. While these sensors are not perfectly accurate, they do provide an interesting source of data for observing year to year variations in solar energy.

To look for variations in solar energy during the past decade, we selected a few of the stations with the most complete data.

As you can see from these graphs, the most obvious feature is the reliable annual cycle in solar energy. Precipitation totals vary widely from year to year, but solar radiation is almost as stable and predictable as a good hard rock. It's this cycle that drives the whole global climate system. Solar energy reaching the ground is approximately three times greater in winter than in summer over Colorado. The rate of change in both spring and fall is quite remarkable. No wonder the seasonal changes in weather patterns are so dramatic.

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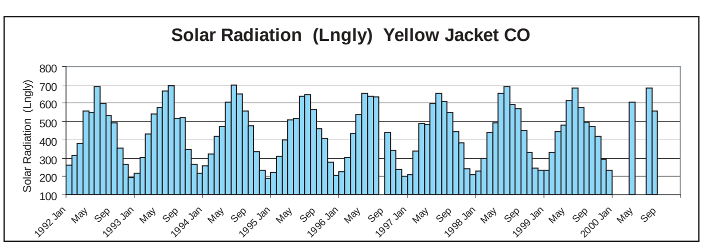
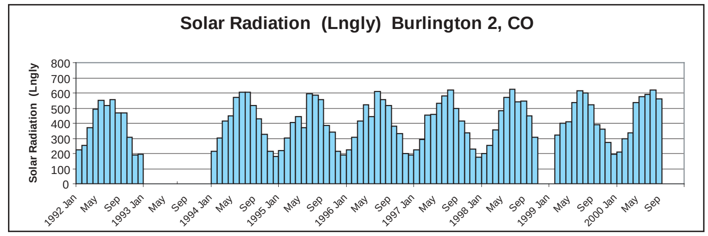
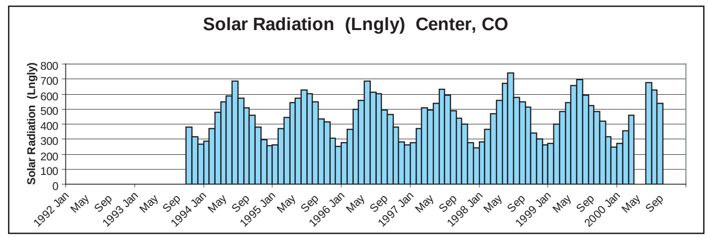
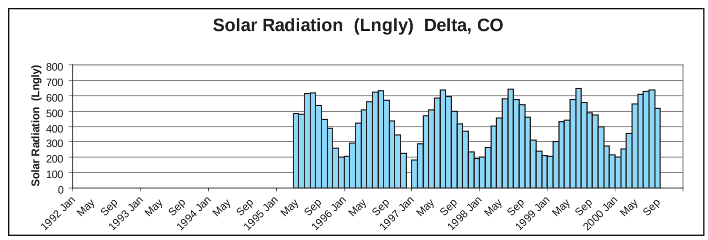
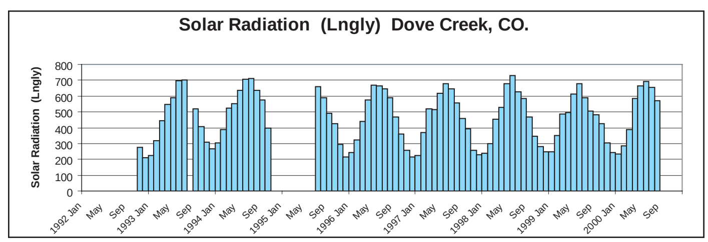
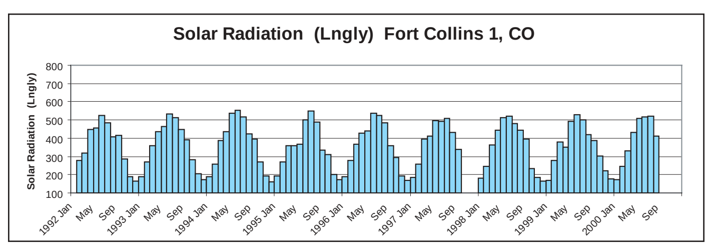


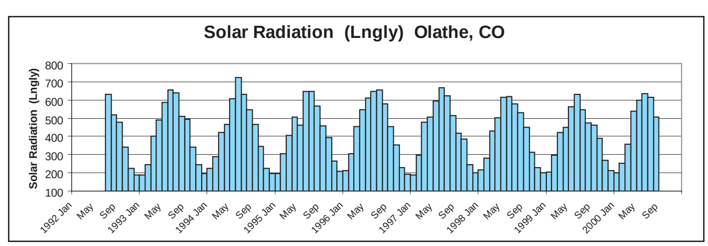












A Time for Time Series *(continued from page 3)*

Some of the important geographic variations in solar energy across the state also appear in these graphs. For example, the Center weather station near the middle of the broad San Luis Valley in south central Colorado is much sunnier than Fort Collins to the north. The latitude accounts for some of this difference, but there is also a big difference in cloudiness between these two sites in both winter and summer.

Can we look at these graphs and detect any significant trends? Well, first of all, nine years is a very short time when it comes to trends. Nine years of solar radiation data is enough to get a good idea of expected average values and the nature of the annual cycle, but it is not long enough to detect long-term trends. Furthermore, the low-cost sensors used for this measurement may not be stable enough over time to discern subtle changes. But we can spot some of the significant variations that appear from time to time and have big effects on agriculture. The spring months of 1995 stand out at most stations. Rather than shooting up in April and May, incoming energy reaching the ground remained nearly constant as dense, persisting cloud cover hung over all but extreme southern and southwestern Colorado. That year, despite abundant moisture, crops got off to a terrible start due to the cool, cloudy weather.

There was also an interesting anomaly this past year. Usually, solar insolation peaks in June. In 2000, however, there was very little cloudiness in July and many stations peaked one month later. In fact, the entire summer had more sunshine than normal with only 1994 showing similar amounts. Both, not surprisingly, were very dry and hot summers.

If you want to keep an eye on solar radiation in Colorado, monitor the COAGMET weather data at http://ccc.atmos.colostate.edu – click on COAGMET.

P.S. Solar radiation is expressed in a variety of units that some find baffling. Here are some of the commonly used units and their conversions.

To convert from	To	Multiply by
BTU per foot^2	Kilowatt-hour per meter^2	3.1525×10^{-3}
BTU per foot^2	Kilojoule per meter^2	11.349
BTU per foot^2	Calorie per centimeter^2 (langley)	0.27125
Kilowatt-hour per meter^2	Kilojoule per meter^2	3600
Kilowatt-hour per meter^2	Calorie per centimeter^2 (langley)	86.04
Kilojoule per meter^2	Calorie per centimeter^2 (langley)	0.02390
To derive	**From**	**Divide by**

Blizzard *(continued from page 1)*

Colorado. We had been away all week at professional meetings and were anxious to get home. It had been mild when we left Fort Collins several days before and none of us were dressed for winter. We arrived on separate flights, but we planned to rendezvous at the airport and drive back to Fort Collins together in their comfortable 4-wheel drive vehicle.

Both of our planes landed safely at Denver International Airport, late but intact. Never before had I landed in such lousy weather. The plane was nearly on the ground before we caught our first glimpse of runway lights directly below us through the swirling snow. We all quietly gave thanks for sophisticated guidance systems – and divine guidance as we taxied to the nearly obscured terminal.

The next few hours went from fun and exciting to challenging, to nerve wracking, to downright scary. Even a good vehicle and excellent highways are no match for the combination of cold temperatures, heavy snow, and strong winds that turn a lovely snowfall into a life-threatening blizzard. We thought if we could just get over to I-25 we could follow a semi. Even if it took extra hours, we'd still be sleeping in our own beds later that night. That wish never quite came to pass. We almost made it to Longmont when the truck we were trying to follow decided to quit for the night. In a way it was a relief to pull off the road and quit battling the hypnotic snowflakes and the wiper blades that froze into blocks of ice every few minutes. We slept fitfully, in 15 to 30 minutes blocks, but we stayed relatively warm and relatively safe. Every 30 minutes or so we ran the engine just enough to warm up our feet and hands. Then we'd shut it down again and try to sleep. All traffic was stopped. All of us travelers were humbled captives of the storm.

(continued on page 5)

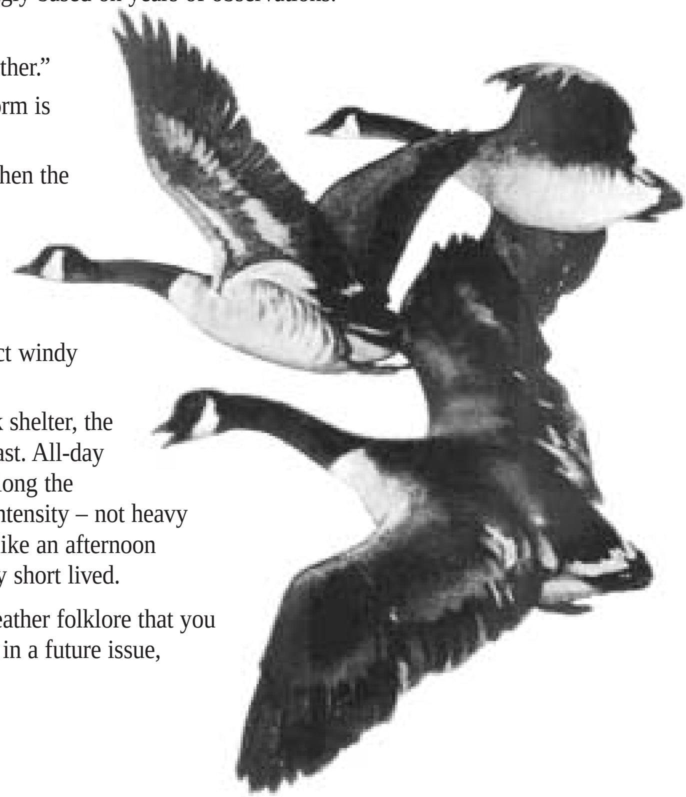
Folklore – Fowl Weather Is Coming

Nolan J. Doesken

I must admit, I'm not much of a bird watcher. But for thousands of years, some people have been watching birds to anticipate changes in the weather. There is a great wealth of weather lore that involves fowl – both domestic and wild. As a child, I was thrilled by the migrations of Canada geese over central Illinois. We wouldn't see them every year, but when large "Vs" cut through the skies high overhead in the autumn, cold weather invariably followed soon behind. Aunt Minerva, the old lady across the street in my home town, would tell us what kind of a winter to expect based on the number of geese we would see, how early in the fall they passed over, and how high they flew. She was convinced that the higher and faster they flew, the harder the approaching winter would be. Now, those blasted geese are everywhere here in Fort Collins, flying in all directions seemingly year round. Why did they quit migrating anyway? Did that mean no more harsh winters?

Here are a few other bits of wisdom that some people have believed strongly based on years of observations. For the most part, the validity of these observations remains unproven.

- "When prairie chickens roost in creek bottoms and timber, expect cold weather."
- "Robins will perch on the topmost branches of trees and whistle when a storm is approaching."
- "A crowing rooster during rain indicates fair weather ahead." However, "When the roosters go crowing to bed, they will arise with watery head."
- "When sea gulls fly to land, a storm is on hand." – either that, or a new landfill just opened for business.
- "When the woodpecker leaves, expect a hard winter."
- "Magpies (common here in Colorado) flying and uttering harsh cries predict windy weather."
- "If chickens go outside in the rain, the rain will last all day. But if they seek shelter, the rain will be brief." I've seen this myself, but I don't think it's really a forecast. All-day rains like the spring and autumn "upslope" storms that we sometimes get along the Front Range in Colorado tend to be steady, long-lasting, but quite light in intensity – not heavy enough to scare the chickens back to the coop. Heavier showers, however, like an afternoon thunderstorm, send all of us scurrying. These storms, however, are normally short lived.



These are but a few of the pearls of fowl weather wisdom. If you have weather folklore that you would like to share with us, we'd love to hear from you. We'll try to include it in a future issue, along with a discussion of the possible validity.

Blizzard *(continued from page 4)*

Before daybreak the next morning, the visibilities seemed to improve a bit as the snow diminished perceptibly. The winds were still strong, and snow still swirled around us. It took some maneuvering to avoid the large drifts, but Tom cautiously worked his way back on the highway. With the illumination of daylight, and with hardly anyone else on the Interstate, we made it home in time for breakfast. We were safe. Others did not fare so well. Hundreds of people spent close to 24 hours on Pena Boulevard caught in deep drifts near the airport. Had we been just 20 minutes later leaving the airport, we would have been there too. The storm was even worse in southeastern Colorado where nearly three feet of wind-driven snow formed huge drifts. In the days that followed, several bodies were found stuck and frozen in the snow. For some, this was their last blizzard.

What blizzards do you remember? Here is a list of some of Colorado's mightiest storms as recorded by more than a century of volunteer weather observers across the state. By no means is this all the blizzards and snowstorms, but certainly some unforgettable ones.

January 11-13, 1888: An extreme Great Plains blizzard brought misery and death from Montana and the Dakotas south into Oklahoma and Texas. Reports are sketchy, but it appeared that portions of eastern Colorado experienced windblown snow followed by frigid cold. Fort Collins reported a temperature of 28°F following the storm. The storm was a catastrophe for cattle and sheep ranchers on the plains as huge numbers of livestock froze to death.

Winter 1899: An incredible barrage of snow-storms totally buried Colorado's central mountains during a 10-week period from late January through

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For Teachers – What Can We Learn in the Snow?

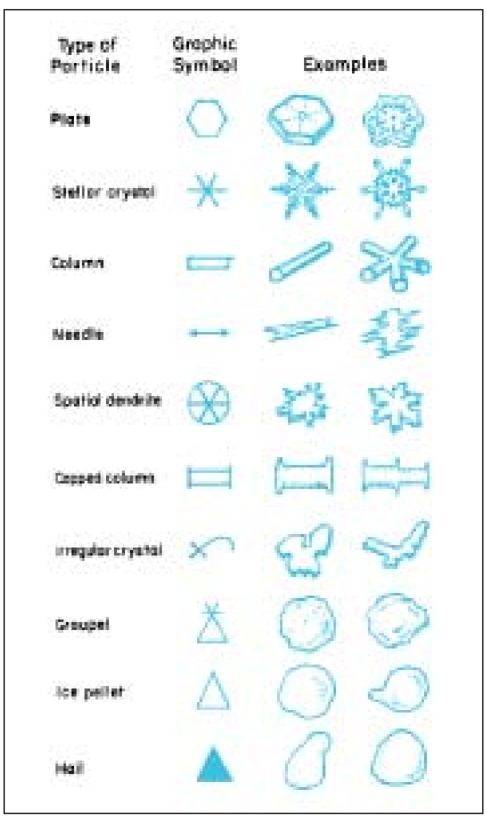
Nolan J. Doesken

Photo by Grant Goodge.

There are colder places than Colorado and there are snowier places, too. But our combination of mountains, plains, high elevations, and interior continental location means that our mountains are snow covered nearly nine months out of the year, and at lower elevations, snows can fall anytime from September to the end of May. You could look at this as a problem. Your kids can't get away with wearing only shorts and t-shirts year round as they do in Phoenix, LA, or Miami. Or you could see this as an opportunity. ***We could study snow.*** I suggest the latter.

You all know that your kids love playing in snow. Why not let them play, and then sneak in a little learning at the same time before they get too cold?

There are so many things you could do with your students in the snow. Here are a few ideas. If it is snowing during the day, even a very light snow, bundle up your students and head outside. Observe the flakes as they fall. Do they fall straight down or at an angle? The wind speed will determine that. The stronger the winds and the lacier the crystals, the steeper the angle of fall. Also, different sizes and shapes of crystals will fall at different angles. Creative students could figure out ways to show this on photographs taken on digital cameras. Under blizzard conditions, the snow will mostly fall sideways. You probably won't get the chance to observe that with your class, because if the snow is doing that your school will probably be dismissed. Hurray!



Common snow crystal forms from the international classification for solid precipitation.

Now see if you can estimate the fall speed of the crystals. Take a measuring tape and a stopwatch. With a little practice, a team of three or four students working together will be able to estimate quite accurately how many feet (or meters) the flakes are falling per second. Dense, compact, or spherical crystals will fall the fastest, while drier, lacier crystals will fall more slowly. If there is no wind and the crystals are falling straight down, expect very light and fluffy snowflakes to fall at a rate of approximately one to four feet per second. Denser, wetter crystals usually fall vertically at a rate of four to six feet per second. If you see crystals falling vertically faster than that, you can be sure they are full of moisture. The fall speed will tell you quite a bit about the nature of the storm and the potential for large accumulations. Faster fall speeds mean faster accumulations.

You can also guess how long it took the snow to reach the ground. Snow-producing clouds are usually between 2,000 and 15,000 feet above ground.

You can also estimate wind speeds by measuring horizontal motion of the crystals. Small, light crystals will be carried along by the wind at speeds nearly identical to the wind speed. You can measure these speeds in feet or meters per second and then convert these into miles per hour or kilometers per hour as a fun little math problem when you're back in your classroom. A few kids may even like the challenge of trying to make those conversions in their heads. Remember that if you are working in English units, 60 miles per hour is equivalent to exactly 88 feet per second. So a 10-mile per hour breeze is just under 15 feet per second.

Another fun thing to do is to watch how the crystals fall. Do they fall in a straight line or do they dance about as they fall. The easiest way to evaluate this is to try to catch them on your tongue. The flakes that fall erratically are a real challenge for even the quickest catcher. If it is snowing heavily with many fine crystals, you will catch them on your tongue even without trying. Then your principal may soon dismiss school, as this is a sign of heavy snow.

OK, now let's catch some crystals so we can look at them closely. Use a black cloth to maximize contrast, but make sure the cloth has been outside so that its warmth won't help to quickly melt the crystals. Look at some crystals. Is each flake a single crystal, or are there a bunch of crystals stuck together? There is no right answer here, since each is possible. Look at the crystals carefully. You may need to do a little homework yourself before doing this exercise so you can be familiar with the many types of crystals that are possible – needles, columns, cups, plates, graupel and, of course, the classic "dendrites" commonly called stellar crystals. What can you tell about the clouds that produced the snowflakes by looking at the crystals? You'll need some reference materials to help you interpret what you are seeing. We recommend our book, *The Snow Booklet: A Guide to the Science, Climatology and Measurement of Snow in the United States.* But there are plenty of other books and teaching resources and some neat information about snow on the Web.

Later you should look at the older snow on the ground. Do those crystals look the same? Can you even identify individual crystals? It turns out that snow crystals on the ground decay quickly or gradually, depending on temperatures and other factors, into forms that look more like little balls of ice. There are a lot of physics involved in this process that snow scientists refer to as "metamorphosis." And you thought only butterflies did that. Not all your students will be interested, but you can at least get them thinking by asking them to recall how the snow feels as they walk through it and how it changes from day to day. You'll realize that at first the fresh snow may be like soft powder, but later it becomes harder and icier. Sometimes you can even walk on top of the snow without breaking through.

How snow crystals change in deep layers of accumulated snow up in the mountains is something that avalanche scientists study and watch very carefully. You may or may not know this, but Colorado has more fatalities from avalanches than any other state. If your school is in or near the mountains, you may have an avalanche expert nearby who could come talk to your class about the amazing characteristics of snow crystals. It isn't just the depth of snow that causes avalanches, but changes of these crystals in certain layers that make the snowpack unstable and vulnerable to avalanches. The sooner your snow-loving adventurers find out about this, the better. It could save their lives.

Have everyone gather around you and cup your hand to your ear. Ask all of your students to listen carefully. What do you hear? Are sound waves affected by snowfall? When snow is falling, and when the ground is coated by fresh snow, sound waves tend to be quickly absorbed. A car traveling down the nearby road may scarcely be audible. Part of the magic of fresh snow is the silence that accompanies it. Later, after the snow ends and the snow settles and compacts, the characteristics of sound begin to change. The snow no longer muffles sound. In fact, sounds may seem to travel much further than usual. This may be due, in part, to the smooth surface of older snow that may help to uniformly reflect sound waves. But it is probably some of the indirect effects of snow that have the largest impact on sound. The air tends to remain very cold just above snow-covered surfaces causing what we call "temperature inversions" where temperatures are coldest near the ground and increase with height above the ground. Winds will tend to be calmer at ground level in the presence of temperature inversions. Calm winds mean no sounds from wind, which makes it possible to hear other sounds more clearly. Cold air is also denser than warmer air. Sound travels more efficiently in a denser medium.

My goodness, we forget the basics. If possible, have your kids measure snow. The fundamental climatological measurements of snow consist of depth of fresh snow, water content of fresh snow, total depth of both new and old snow, and its total water content. Weather observers throughout the U.S. measure the accumulation of fresh snow each day using the simplest of tools – a ruler or yardstick. The U.S. continues to take measurements in English units, but someday that should change.

You can learn a lot by measuring how snow falls. Photo by Grant Goodge.

Measuring the depth of fresh snow seems so easy, and it is. All you have to do is stick a ruler in the snow and measure the depth, right? That's right, and when the winds have been calm, the skies cloudy, and the temperature well below freezing we could all go out with our rulers and come up with about the same answer. However, part of the exciting mystery of snow is its mobility. It doesn't stay put. When the wind blows, snow moves. It swirls about and lands unevenly. Windblown snow is compacted, while snow falling in protected locations remains more fluffy and uncompacted. Furthermore, snow changes with time as crystal structures deep within the snow gradually change. Just because you had six inches of snow on the ground last night doesn't mean you'll still find six inches this morning. And then, of course, there is the matter of melting. Snow can melt from beneath, if the ground is warm, even when the air is well below freezing. Likewise, snow can melt from the top as soon as the sun hits it, especially if dirt or other dark objects stick up through the snow to absorb solar energy. Winds and moist air will also hasten snowmelt. What this all means is that measuring snow is like shooting at a moving target.

How much time you will spend measuring snow probably depends on how much you like snow yourself. The simplest exercise is simply to have each student measure the total depth of snow with a yard/meter stick but from different locations around the school. You could even make a local map of snow depth around your school and discuss the wind patterns, ground surfaces and slopes, building locations and vegetation patterns that contribute to the observed snowfall pattern. Then you could have your

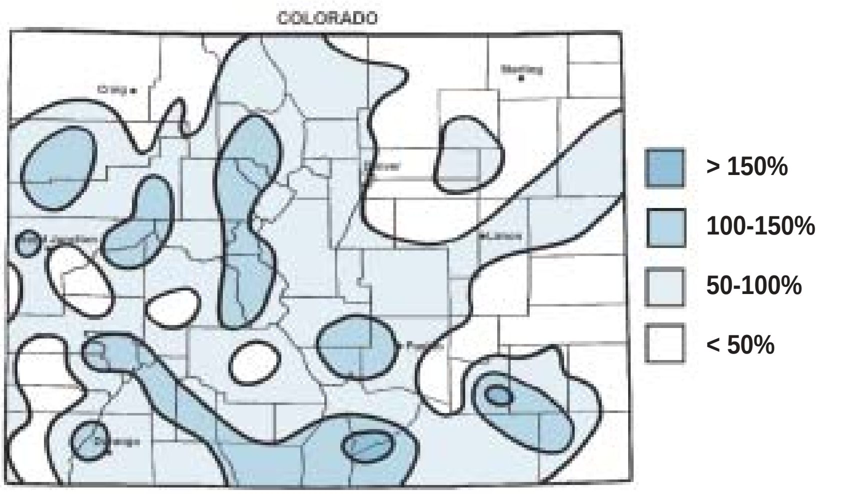
(continued on page 18)

Colorado Climate in Review

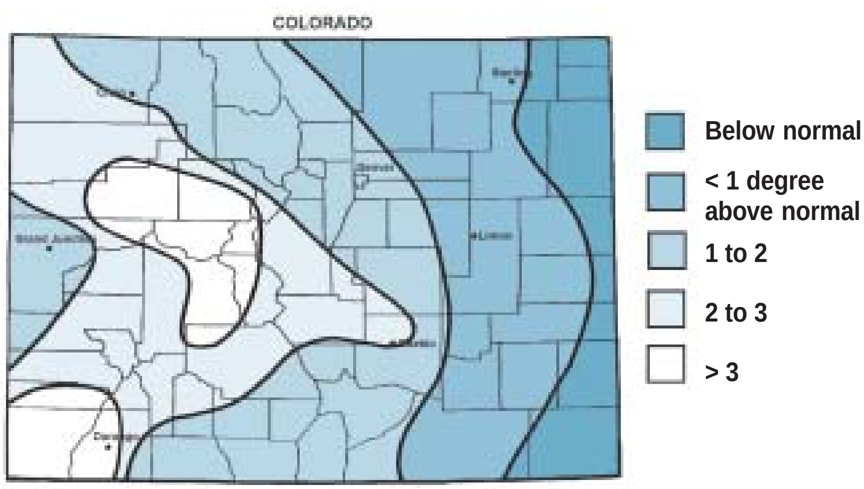
June 2000

Climate in Perspective

June was topsy-turvy with strong winds and huge swings in temperature, especially east of the mountains. Early June, normally cool and damp, was very hot and dry. Late June, normally hot and dry, was cool and damp. Despite a strong jet stream and several pronounced storm systems, hail and tornadoes were few. In fact, northeast Colorado, which is accustomed to severe storms in June with generous rainfall to help crops grow, experienced one of the driest Junes in recorded history with very little severe weather. Particularly noteworthy were a pair of very large forest fires in the Front Range foothills (the High Meadows fire southwest of Denver and the Bobcat Gulch fire west-northwest of Loveland) which erupted early in June and spread rapidly in the face of parched swirling winds, only to be extinguished by a surprise late season snowfall.



June 2000 precipitation as a percent of 1961-1990 average.



June 2000 temperature departure from 1961-1990 average, degrees F.

Precipitation

Precipitation totals for June were less than average over most of Colorado. Much of eastern Colorado received less than half of the June average, as did portions of the Western Slope. Several weather stations in eastern Colorado and on the Western Slope measured less than 0.50 inches for the month. With the frequent dry winds, this was scarcely enough moisture to moisten the soil or grow any grass. But not all areas were dry. Frequent showers late in the month left some areas of southern Colorado above average. Some weather stations in the central mountains also were wetter than average. Vail received over two inches, most of which fell in the last half of the month.

Temperature

Early in the month it looked like Colorado was on its way to a real scorcher as temperatures climbed well into the 90s on several days. However, several strong cold fronts brought periods of sharply cooler temperatures with highs only in the 50s and 60s later in the month over eastern Colorado and the Front Range. The result was near average temperatures for the month as a whole over eastern Colorado while the western half of the state ended up two to three degrees above average.

June Daily Highlights

1-5 Generally dry and hot over western Colorado but pleasantly cool but windy east of the mountains except on the 3rd when temperatures soared briefly.

6-8 Hot and dry statewide. The remnants of the mountain snowpack melted quickly under bright sunshine and mountain temperatures in the 70s. The Steamboat Springs weather station hit 90°F on the 7th. Clouds and winds increased in western Colorado on the 8th.

9-10 A cold front swept across the state bringing relief from the early heat but with only a few light showers, mostly in the mountains.

11-15 Low humidity and high winds helped two forest fires along the Front Range to spread rapidly, consuming dozens of homes west of Loveland and southwest of Denver. The fires spread most rapidly on the 12th and 15th when temperatures were highest and relative humidity fell to 10 percent or less.

16-17 A strong cold front swept southward across the state late on the 15th with 40-50 m.p.h. winds and with temperatures dropping 30-40 degrees. Little or no precipitation accompanied the front, but low clouds and drizzle developed later on the 16th over northern Colorado increasing to a steady, cold rain which eventually turned to snow in the northern mountains and eastern foothills early on the 17th, mercifully bringing the fires under control.

18-19 A large trough of low pressure crossed the state bringing cool and unsettled weather. Precipitation was widespread over northwest Colorado but dissipated as it crossed the mountains. Meeker picked up over an inch of moisture and three-quarters inch hail on the 19th.

20-21 Mostly dry but cool.

22-24 Warmer with weakening winds aloft and increasing humidity. A few severe thunderstorms developed over eastern Colorado on the 22nd.

25-26 Chilly air from the north collided with warm moist air from the south to produce the only widespread precipitation event of the month. A few stations in southeastern Colorado received over an inch of rain on the 26th.

27-30 Conditions remained unsettled, with scattered thundershowers each day, especially over southern Colorado. Temperatures gradually moderated and returned to average by the end of the month.

June 2000 Monthly Extremes

Description	Station	Extreme	Date
Precipitation (day):	LaJunta 20S	1.62"	Jun 27
Precipitation (total):	Flagler	3.21"	
High Temperature:	Yuma	105°F	Jun 7
Low Temperature:	Sargents	19°F	Jun 20

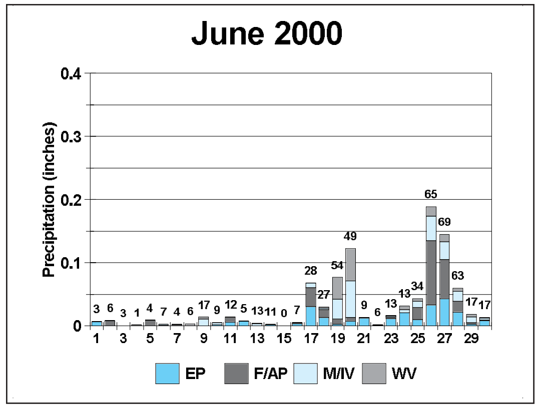
July 2000

Climate in Perspective

July is normally the hottest month of the year, and that was certainly the case in 2000. A large high-pressure ridge stayed in the region for most of the month. Daytime temperatures climbed into the 90s at lower elevations nearly every day but dropped back into the 50s and lower 60s by morning. July is also the wettest month of the year based on total statewide precipitation, but not this year. Thunderstorms developed on many days, but widespread precipitation was limited to a brief period in mid July.

Precipitation

Some of Colorado's eastern plains received much-needed moisture in July. From Yuma south to Springfield, many locations got at least 3 inches of rain. Yuma's 4.91" total was the greatest in the state, although 3.70" fell in just one day. A few areas of central Colorado also got more rainfall than average.

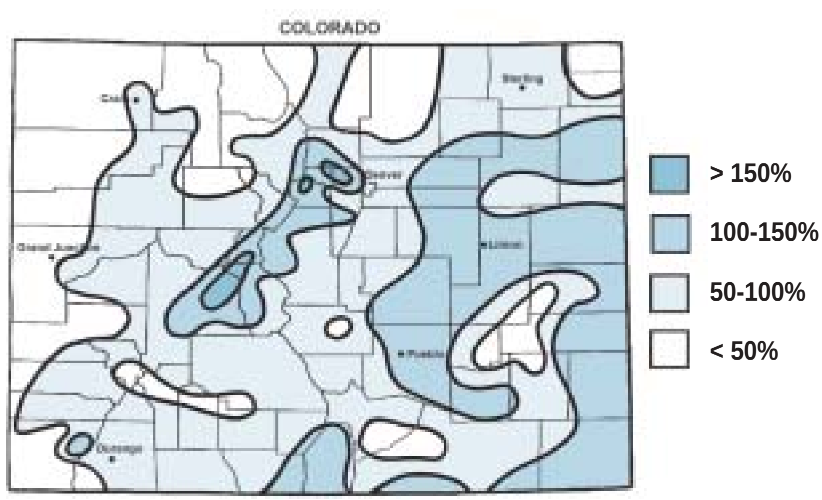


Statewide Average Daily Precipitation graph(s) (above and throughout this article) shows relative amounts of precipitation for each region. Label on each column indicates percent of stations with measurable precipitation for each day.

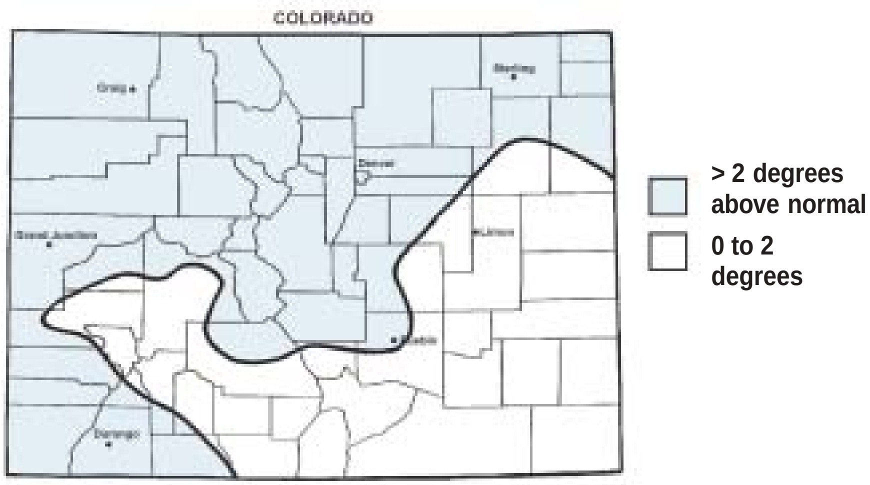
For most of the state, however, July was drier than average. Much of the Western Slope as well as northeastern Colorado were extremely dry. The Greeley station on the campus of the University of Northern Colorado reported just 0.36 inches for the month, the second driest July in 31 years of record.

Temperature

Temperatures for July were above average statewide. The warmest areas, compared to average, were found over northeastern Colorado and over extreme southwestern counties. Denver, Boulder, Greeley, Fort Morgan, and Sterling all ended up at least three degrees F above average. No new record highs were set, but above-average temperatures persisted day after day. Denver, for example, saw the mercury reach 90°F or greater on 25 days in July.



July 2000 precipitation as a percent of 1961-1990 average.



July 2000 temperature departure from 1961-1990 average, degrees F.

July Daily Highlights

1-7 Hot and dry with southwesterly winds aloft. Isolated thunderstorms developed most days but produced little rain. However, a storm managed to drop nearly two inches of rain and large hail on Lamar late on the 2nd. The 4th of July was sunny and appropriately hot and dry. A thunderstorm east of Sterling dropped a large tornado near Fleming/Dailey on the evening of the 5th, causing significant local damage.

8-9 A pulse of tropical moisture moved into Colorado from Arizona and New Mexico triggering numerous thundershowers over and near the mountains.

10-12 Hot weather continued with scattered thunderstorms primarily east of the mountains. Large hail fell at Eckley on the 10th, and the Pueblo airport got 1.95 inches of rain on the 11th.

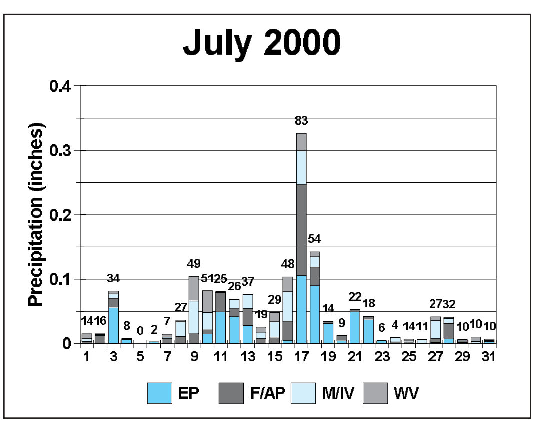
13-15 Mostly dry and hot statewide.

16-17 A cold front brought a much-appreciated break in the hot weather over much of Colorado and also triggered widespread and locally heavy rains. A few tornados were spotted over northeastern Colorado. The heaviest rains of the summer fell east of the mountains. Many locations on the plains picked up at least an inch of rain, while temperatures only reached into the 60s and 70s over northeast Colorado on the 17th.

18-21 Dry over western Colorado with seasonally warm temperatures statewide. Scattered and locally heavy storms developed east of the mountains, most numerous 19-20th. Yuma picked up 3.70" from a local downpour.

22-26 Continued quite hot with high-based afternoon thundershowers producing little rainfall. A major wildfire erupted in Mesa Verde National Park closing the park and spreading a large plume of smoke over the region.

27-31 High pressure aloft shifted westward giving most of Colorado northerly winds aloft. Smoke from large forest fires elsewhere in the West covered Colorado in a thickening haze. A few thundershowers developed each day, but little rain reached the ground.



July 2000 Monthly Extremes

Description	Station	Extreme	Date
Precipitation (day):	Ralston Res.	3.72"	Jul 17
Precipitation (Total):	Yuma	4.91	
High Temperature:	Las Animas	106°F	Jul 4
	Ordway	106°F	Jul 7
Low Temperature:	Sargents	24°F	Jul 4

August 2000

Climate in Perspective

Smoke-covered skies gave visual evidence to the many large forest fires that burned out of control during August over Montana, Idaho, and other western states. Fires continued to burn early in the month on Mesa Verde, but Colorado was spared the worst of it despite continued hot and dry weather. Humidity increased in mid August, and afternoon thundershowers developed each day during the last half of the month bringing at least temporary relief to what was otherwise one of the hottest and driest summers that Colorado had experienced in several years.

Precipitation

Rainfall patterns in August were spotty, but wet areas outnumbered the dry by almost two to one. Some parts of southeastern Colorado recorded less than 25 percent of the average August precipitation while areas from Colorado Springs and Denver northeast to Fort Morgan were much wetter than average. The Sedgwick-Julesburg area of northeastern Colorado, severely impacted by drought this year, finally received beneficial rains. Except for extreme northwestern Colorado, the majority of the mountains and western valleys were wetter than average.

Temperatures

The hot summer of 2000 continued well into August. Daily maximum temperatures reached or exceeded 90°F in Denver 15 out of the first 16 days helping establish a new record for the most days in a year with temperatures of 90 or higher. The entire state ended up three to five degrees above the 1961-1990 average with the warmest areas in extreme eastern, southwestern and northwestern Colorado.

August Daily Highlights

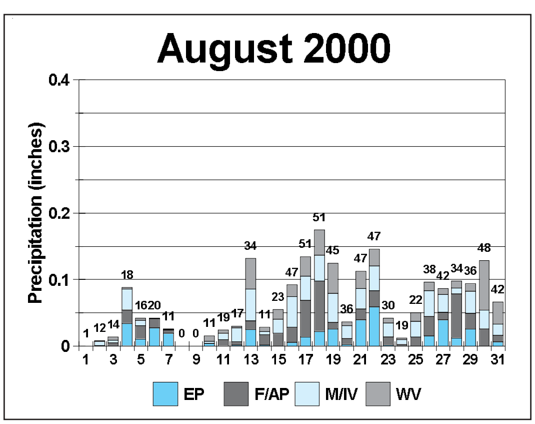
1-3 Mostly dry and very hot, especially over western Colorado. Hayden hit 95°F and Meeker climbed to 98°F on the 1st. A few isolated thundershowers developed. Visibilities were reduced as smoke from western forest fires crossed the state.

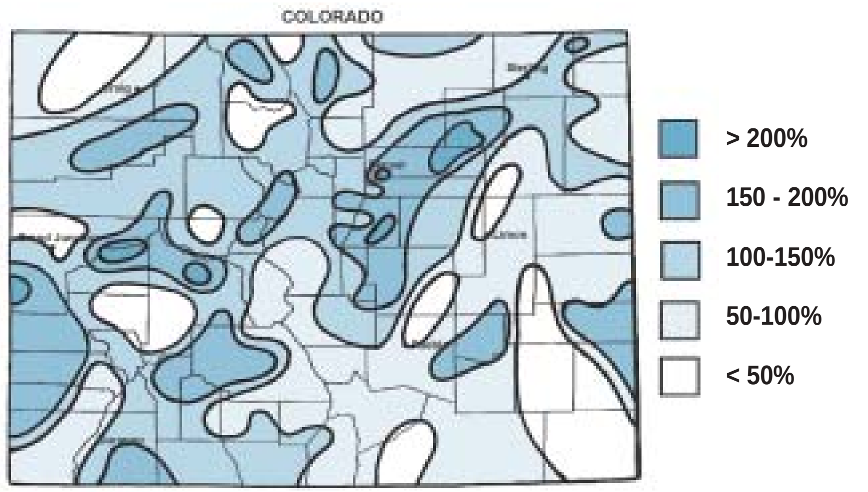
4-5 Temperatures dropped slightly as an upper-level disturbance triggered some thunderstorms. Fort Morgan received 1.89" from a storm on the 4th. Crested Butte picked up 1.69" from a heavy localized storm.

6-11 Hot and dry weather persisted with occasionally smoky skies.

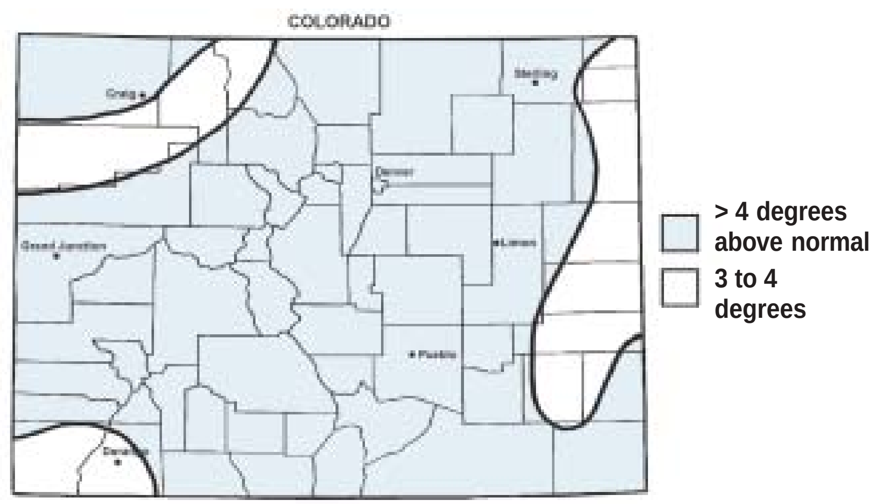
12-16 More hot weather with temperatures still flirting with the 100°F mark. Holyoke hit 104°F on the 14th and Lamar followed with a 105°F reading on the 15th. Moisture increased over western Colorado fueling afternoon showers and thunderstorm from the mountains westward. Leadville recorded 1.10" of rain on the 13th.

17-18 Cooler statewide with more widespread shower activity. Parts of Aurora received over 3" of rain in two days with locally heavier amounts. A furious storm brought hail, high winds and 2.65" of rain to Fort Carson (south edge of Colorado Springs).





August 2000 precipitation as a percent of 1961-1990 average.



August 2000 temperature departure from 1961-1990 average, degrees F.

August 2000 Monthly Extremes

Description	Station	Extreme	Date
Precipitation (day):	Colo. Spgs.	2.99"	Aug 28
Precipitation (total):	Bonham Res.	6.80"	
High Temperature:	John Martin Dam	106°F	Aug 16
Low Temperature:	Meredith	26°F	Aug 19

19-28 Not too hot but still consistently above average with numerous thundershower development each day. Some of the storms dropped locally heavy rains such as the 1.52" rainfall at Holly on the 20th and 2.99" at Colorado Springs on the 29th. Finally, the forest fire danger began to subside across the state.

29-31 A weak cold front dropped temperatures a bit and brought a faint hint of the approach of autumn. Daily convective showers continued especially over and near the mountains. Yellow Jacket picked up over two inches of rain in two days.

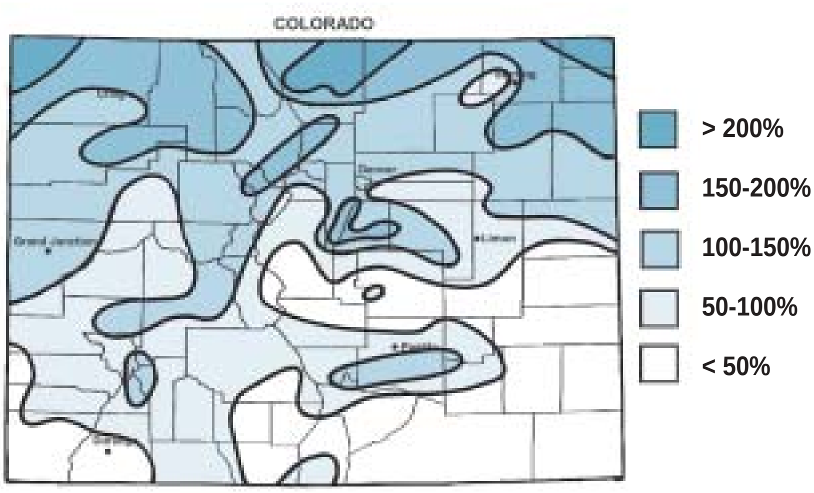
September 2000

Climate in Perspective

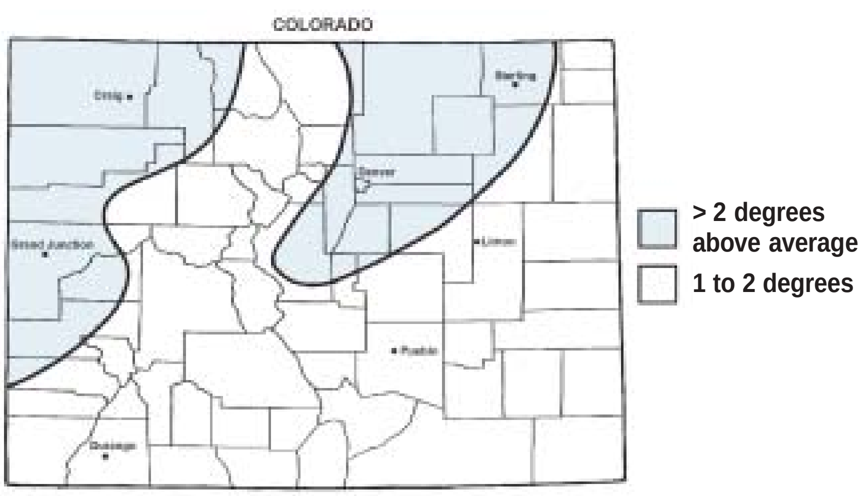
At first it seemed like the hot, dry summer of 2000 would never end as temperatures continued to climb into the 90s well into the month. But when the change came, it was very clear that it wasn't summer any more as welcome rains quickly gave way to the first snow of the year and a killing freeze that affected practically the entire state.

Precipitation

Interstate 70 was the approximate boundary between wetter than average conditions in September over northern Colorado versus drier than average across the southern half of the state. Areas that had been extremely dry earlier in the year such as Larimer and Weld counties in north central Colorado and Phillips and Sedgwick counties in extreme northeastern were blessed with about double their average precipitation. Much of northwestern Colorado received well over 150 percent of average. Most of this moisture fell in the period for September 18-24. Southern Colorado was missed, however, and several areas ended up with less than 50 percent of average. In fact, extreme southwestern Colorado, the San Luis Valley and portions of southeastern Colorado only picked up about 10-30 percent of average.



September 2000 precipitation as a percent of the 1961-1990 average.



September 2000 temperature departure from 1961-1990 average, degrees F.

Temperatures

Cold weather late in September and an early, hard freeze were still not enough to keep September from being the 12th consecutive warmer than average month for Colorado. Most locations ended the month one to three degrees Fahrenheit above average with the warmest areas found across southern portions of the state.

September Daily Highlights

1-6 High pressure remained fixed over the Texas panhandle, while a trough of cool, unstable air weakened as it approached from the Pacific Northwest. Southwesterly winds aloft were quite strong through the period. Fairly cool on the 1st, especially over northern and western Colorado, with scattered thunderstorms. Then mostly dry 2-3rd with a gradual warming trend. Very hot temperatures returned the 4-6th with a few scattered but mostly light thunderstorms. Lamar and Las Animas reached 103° and 104° F, respectively, on the 6th.

7-9 Pacific cool fronts moved through in rapid succession bringing cooler temperatures and more shower activity. Parts of southern Colorado picked up from 0.10 to 0.50" of precipitation during the period while northern areas and the I-25 corridor got less.

10-16 Abundant sunshine statewide with no precipitation. Hot summer temperatures continued to roast Coloradans at lower elevations while mountain communities enjoyed sunny warm days but cool nights with low temperatures dropping near the freezing point

17-18 Increasing clouds and turning cooler over western Colorado on the 17th as a small upper-level low-pressure area approached. Still hot east of the mountains. Showers developed over much of western Colorado ending early on the 18th. Rainfall was generally light, but the Uncompaghre valley picked up significant moisture. Montrose reported 0.76". Eastern Colorado remained dry, but the cooler temperatures marked the end of the hot summer of 2000.

19-25 Windy, cooler and unsettled on the 19th as chilly autumn air moved southward out of Canada. Significant and welcome rains fell over northeastern Colorado overnight into the morning of the 20th. Holyoke reported 1.03". The 21st was pleasant east of the mountains, but widespread rains and thunderstorms moved into western Colorado continuing on the 22nd spreading eastward. Some rainfall totals were quite large. Steamboat Springs measured 1.70" for the storm. Cold, wet weather continued as a large, cold high-pressure area over Montana combined with a low-pressure area over Utah. Temperatures dipped to near the freezing point on the 23rd and rains changed to snow over many portions of northern Colorado and continued into the 24th. The first snow of the season brought just a few inches to most areas. However, Larimer County was hit hard by 6 to 15 inches of heavy snow. Trees still in full leaf cracked under the load, leaving some residents without power. As skies cleared later on the 24th, temperatures dropped into the 20s by morning on the 25th, bringing the 2000 growing season to a close.

26-30 September ended with lots of sunshine and a gradual return to above average temperatures. Some might call this “Indian Summer” following the first snow and freezing temperatures on the 24-25th. The dry weather was interrupted on the 29th as an upper air disturbance crossed the state from the west triggering showers and thundershowers most numerous in the mountains. Several weather stations in central and southern Colorado received about 0.25" of moisture.

2000 Water Year in Review – October 1999-September 2000

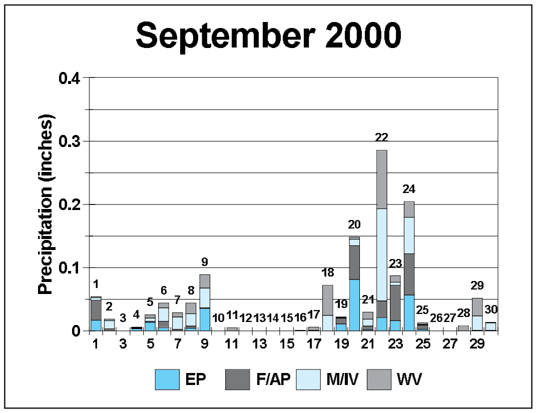
Temperature Characteristics

The 2000 water year will go down as one of the warmest in recorded history for Colorado. Temperatures were above average statewide for every month during the year, which doesn’t happen very often. In particular, the winter months of November, January, and February were extremely warm – at least 6° F above average statewide. Many locations that normally experience subzero temperatures at least a few times each winter never even came close to the zero mark. Winter utility bills were extremely low as mild temperatures teamed with generous sunshine.

Spring and summer temperatures were not so extreme but remained consistently above average everywhere in Colorado. A few cool episodes were noted, as evidenced in the daily temperature graphs for Denver and Grand Lake. However, these episodes were few and far between and very brief. Daily

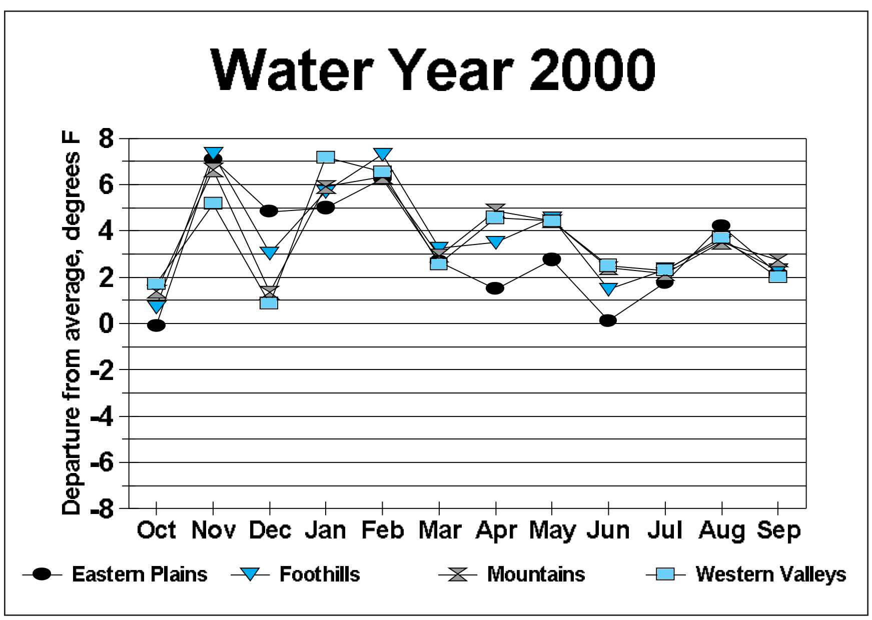
September 2000 Monthly Extremes

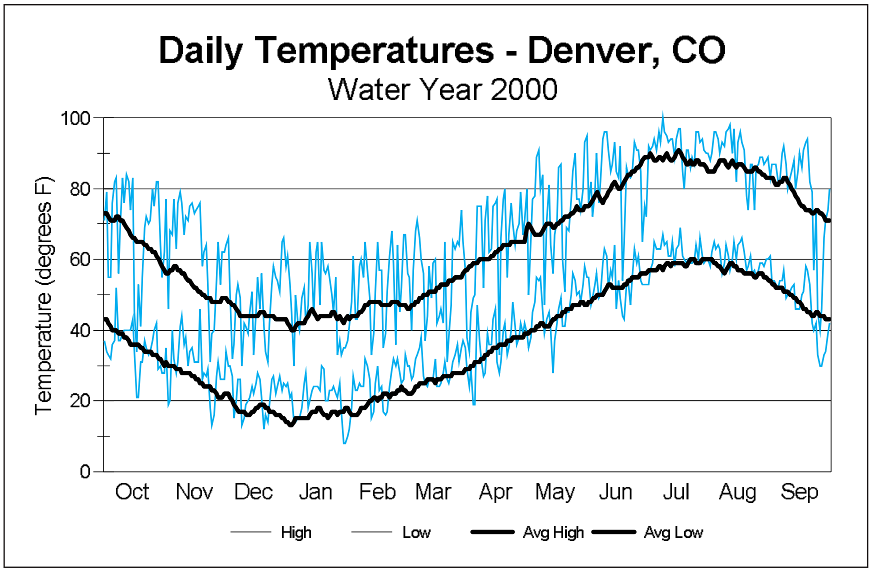
Description	Station	Extreme	Date
Precip. (day):	Steamboat Springs	1.70”	Sep 22
Precip. (total):	Buckhorn Mountain	3.24”	
High Temperature:	John Martin Dam	104°F	Sep 6
Low Temperature:	Sugarloaf Dam	9°F	Sep 25

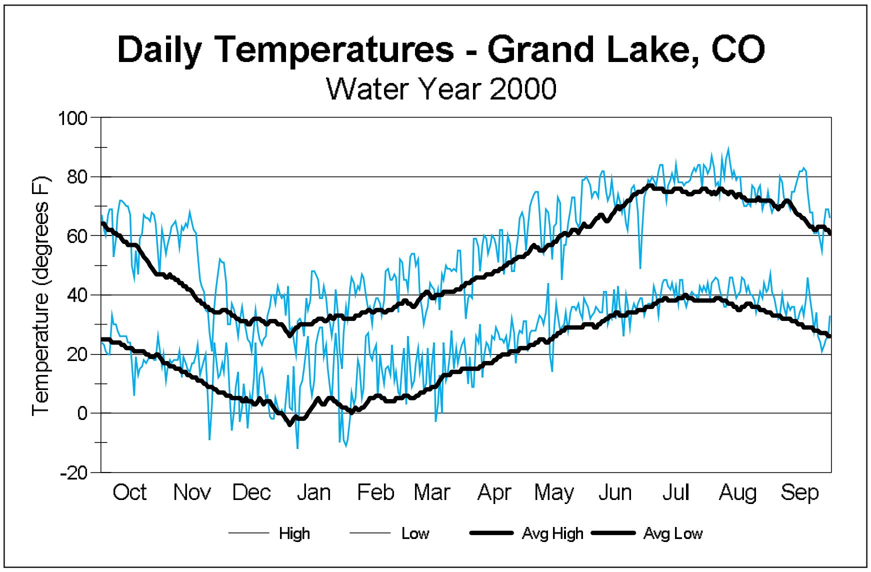


temperatures were above average at the old Denver Stapleton weather station 258 out of 365 days throughout the year.

For the year as a whole, statewide temperatures ended up more than three degrees F above the 1961-1990 average. That may not sound like much, but that ranks this year among the warmest in recorded history. We do not have a complete history of statewide temperatures assembled for the water-year calendar, but based on comparisons at a few stations, only 1934







and 1954, both severe drought years, were comparable or slightly warmer. The most recent very warm year was 1981 but the mean annual temperature that year was a full degree cooler than this year.

Precipitation Characteristics

Historically, hot weather usually accompanies dry conditions, and that was certainly the case this year. October, November, and December were each much drier than average over most areas of the state. Winter recreation activities were reduced as a result of the poor start to the winter snowpack. Mountain snow conditions improved in January and February. A very wet March helped accumulations to almost get back to average. April precipitation totals varied greatly across the state. May and June were both very dry while July was only better in parts of the state. August and September did bring above-average rainfall to some areas, but other parts of the state remained very dry. Overall, precipitation totals for the October through April period, which represents the winter snowpack accumulation and soil moisture recharge period for Colorado, really weren't too bad as much of eastern Colorado was near or above average. The northern and central mountains were average to slightly below. Very dry conditions (less than 70 percent of average) were observed along the Front Range north of Denver to Greeley and Fort Collins and over several areas in western and southern Colorado. For the second year in a row, winter precipitation totals were well below average in Colorado's southwestern mountains from Telluride to Wolf Creek Pass.

Beginning in May, moisture conditions deteriorated rapidly. May and June, normally a wet time of year over northern and eastern Colorado, were extremely dry. The weather station south of Sedgwick in extreme northeastern Colorado recorded only 0.39" in two months compared to an average of 6.53". This was the driest late spring in recorded history in some areas. As a result, the quality of the winter wheat crop deteriorated rapidly, grasslands failed to green up and produced very little forage, and other cultivated crops also struggled under this drought stress. The dry and warm May and June also played a very major role in setting the stage for the extreme wildfire danger and subsequent huge fires that ignited in June.

July, August, and September all brought more precipitation to the state but only some areas felt the benefits. Overall, growing season precipitation (May through September, 2000) was below average for practically the entire state. Some of southeastern and extreme northeastern Colorado reported less than 50 percent of the 1961-1990 average. Haswell ended up with just 25 percent of its average growing season precipitation while Holyoke got 38 percent. A few parts of the state fared much better. Colorado's central mountains were actually wetter than average. Twin Lakes, south of Leadville in Lake County, totaled 141 percent of average. Local areas in Adams, Douglas, and Elbert Counties also fared well, but for the state as a whole, dry areas greatly outnumbered the wet ones.

For the year as a whole, statewide precipitation was 87 percent of average. While Colorado has seen years much drier that this, it has been a long time. 2000 was the driest year since 1977 with only 1989 and 1994 coming close. That year, winter snowpack in the mountains was the lowest on record contributing to extreme drought that affected water supplies over much of the state.

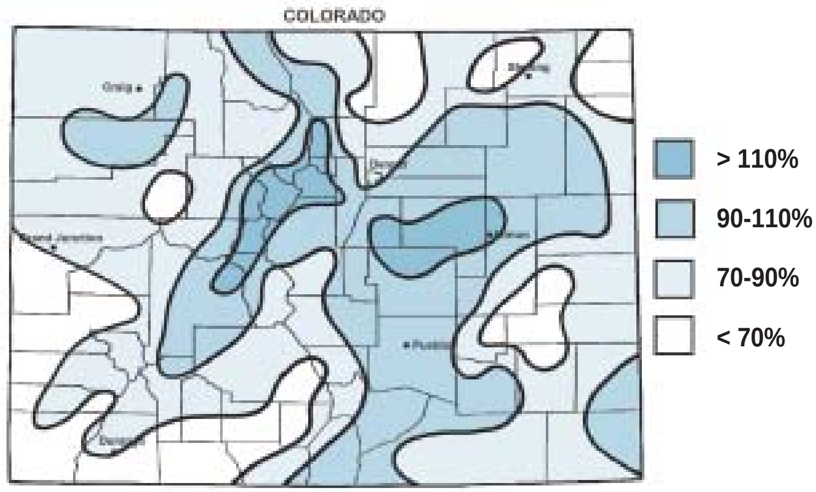
Overall Assessment

The 2000 water year seemed drier than it was. The combination of consistently above average temperatures, a very dry spring and early summer, abundant solar radiation, and moderate winds increased evaporation rates. Less precipitation and more evaporation means more rapid drying. The very mild winter also meant that little or no snowpack accumulated in the foothills and western plateaus. While high-elevation snowpack accumulation was close to average at the end of the winter, the snowpack did not extend down to the intermediate and lower elevations that constitute a much larger portion of the state. Lower areas dried out very quickly in the spring, contributing to the high fire danger.

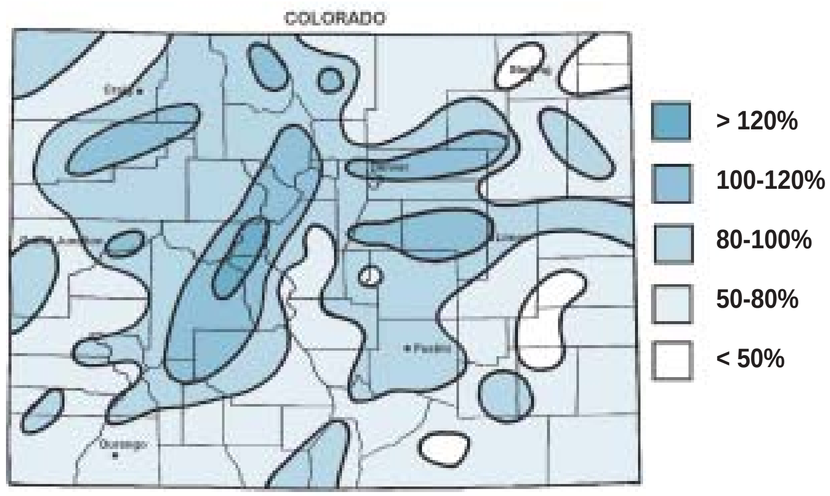
After the wet summer of 1999, Colorado reservoirs were in great shape going into 2000 with many full to capacity. With such a high demand for water, however, reservoirs were quickly depleted during late spring and summer of 2000, particularly the agricultural reservoirs on the plains of northeastern Colorado. Fish populations were at risk at a number of reservoirs prompting special temporary fishing regulations to encourage harvesting fish. Overall, reservoir storage went from 137 percent of the long-term average on October 1, 1999 down to 100 percent of average at the end of the year. While stored water volumes were still adequate in many parts of the state, this is nevertheless a very large one-year loss representing a depletion of well over 500,000 acre-feet of water.

With the warm winter and spring, winter runoff and streamflow were greater than usual. Most streams reached their snowmelt runoff peaks in May and then dropped off quickly. Some streams actually went dry by early to mid summer. Stretches of the South Platte River in northeastern Colorado were completely dry. The Little Thompson River at Pinewood Springs went completely dry, creating a real problem for that small community. The rains of late August and September were indeed welcome

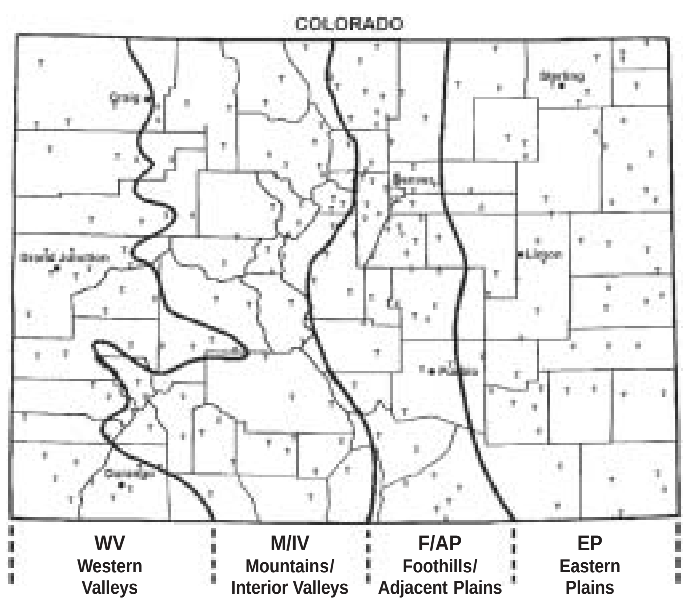
Can we blame anything for the heat and lack of precipitation? Some might say it is the evidence of global warming. Others point the finger at La Nina (cooler than average ocean surface temperatures in the tropics west of South America) as the culprit. Still others simply said, “We’re overdue for a drought.” In truth, there are no simple answers. Variability in climate from one year to the next is one of the great challenges that we face. La Nina was in place in 1999, but Colorado ended up with a very wet year, despite forecasts of likely dry weather. The cold phase of the El Nino Southern Oscillation persisted in 2000 and likely did contribute in part to the weather patterns that we experienced. Likewise, temperature anomalies in the northern Pacific Ocean also contributed. As for global warming, not everyone was sweltering in the heat. Even as Colorado suffered through a hot summer, the east coast and Mid Atlantic states enjoyed one of their coolest summers in many years.



Water Year 2000 (Oct. 1999 - Sept. 2000) precipitation as a percent of 1961-1990 average



Summer 2000 (May - Sept.) precipitation as a percent of 1961-1990 average.



T = Temperature/Precipitation O = Precipitation site only

Blizzard *(continued from page 5)*

March 1899. Aspen and Breckenridge were among the mountain communities that were totally isolated for up to two months as all railroad traffic was blockaded. Some mountain residents who had become accustomed to the efficiency of heating with coal found themselves without fuel. During one six-day storm in early March, the Breckenridge weather observer measured over 70 inches of snow. By the end of March he reported drifts in the mountains up to 200 feet deep. The weather station at the Ruby mining camp near Crested Butte reported 249 inches of snowfall in March. That value still stands as the record monthly snowfall for Colorado.

December 25, 1982 blizzard. Photo taken by Walter Johnson, U.S. Bureau of Reclamation.

December 1-5, 1913: The worst snowstorm of recorded history for the Colorado Front Range from Raton, NM, to Cheyenne, WY. Dozens of trains carrying hundreds of passengers became stranded in many areas of the state. Roofs collapsed (see the article on "Snow Loads" in this issue on page 20) under the weight of nearly four feet of wet snow in Denver.

April 14-15, 1921: While Denver and other Front Range cities received a combination of cold rain and wet snow, an incredibly heavy snow fell in the foothills and mountains of Colorado. It was the greatest snowfall in 24 hours ever recorded anywhere in North America. 76 inches fell at Silver Lake west of Boulder. The snow contained more than five inches of water. Other areas between Cripple Creek and the Wyoming border reported up to 60 inches of snow from this brief but intense storm.

1930: The decade of the infamous Great Depression and "Dust Bowl" kicked off with a viciously cold January with temperatures below zero much of the month. Then a brief but wicked blizzard hit eastern Colorado November 19-20, leaving drifts up to 10 feet high in Burlington with larger drifts on the surrounding open prairie.

November 2-6, 1946: At least 13 people lost their lives as up to 50 inches of snow fell from a long-lasting early blizzard. Residents of eastern Colorado were totally isolated for many days until warmer weather helped melt the early snow.

January 1-6, 1949: One of the worst combinations of cold temperatures, heavy snow, and several days of howling winds buried houses and barns from near Fort Collins and Greeley northeastward across much of Nebraska. Thousands endured harrowing experiences to survive this storm. When winds finally diminished, an extensive airlift was performed over Nebraska to carry hay to stranded livestock and to bring food and fuel to residents isolated by this remarkable storm.

December 29-31, 1951: A furious onslaught of heavy, wet snow and high winds pounded all of western Colorado from the high mountains down to the low valleys. Even normally snow-sparse areas like Grand Junction were buried under deep snow. With a sudden deposit of more than six feet of wind-packed snows up in the high country, avalanches went wild. Mountain highways were closed for days over almost every pass.

March 10-11, 1977: Following months of drought, a sudden spring blizzard packing winds of more than 70 m.p.h. clobbered east central and northeast Colorado. At least nine people lost their lives along with many livestock. Drifts of snow were combined with layers of blown topsoil following months of very dry weather.

December 24, 1982: Denver's infamous Christmas Eve Blizzard made for the whitest and quietest Christmas in history for much of the Front Range. Two to three feet accumulated on the level in downtown Denver. Thousands of travelers were stranded for days. Many of Denver's neighborhood streets remained impassable for one to two weeks. Other areas of Colorado also were affected, and several people lost their lives after becoming lost or stuck in the storm.

February 11-20, 1986: A siege of heavy snow hit the mountains as flood-producing storms pounded California. Several feet of snow accumulated in most mountain communities. The combination of deep snow and high winds resulted in hundreds of avalanches.

(continued on page 19)

Can a Megadrought Occur in Colorado?

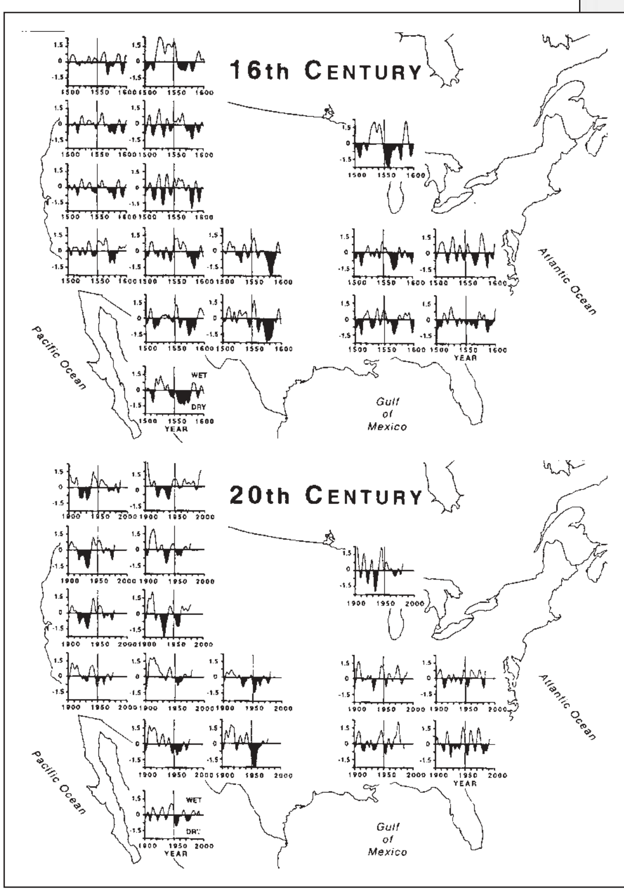
Roger A. Pielke, Sr.

The 1930s were the time period of most serious long-term drought in Colorado since weather records were collected beginning in the later 1800s. The article by Tom McKee, Colorado State Climatologist from 1974 to 1999, and Nolan Doesken, Assistant State Climatologist from 1977 to present, which appeared in our Winter 1999/2000 issue, illustrates historical Colorado drought. However, is this as bad as it can get?

The short answer is no! Not by a long shot. In the March 21, 2000 issue of *EOS*, which is a publication of the American Geophysical Union, research scientists David Stahle and colleagues of the Tree-Ring Laboratory at the University of Arkansas reported on a megadrought in the 16t[h] Century that occurred over large parts of North America including Colorado. This drought lasted for decades, and far exceeded any drought over North America for at least the last 500 years! This drought was part of the Earth's natural climate system and cannot be explained by any human causes.

This natural drought is frightening. And if it happened today, are we prepared to adapt to such extreme, long-term dry conditions? The answer is no. We are only resistant in our municipal water supplies, for example, for a couple of years. Plans should be made today for such an occurrence. The challenge is to develop an environmentally sensitive, yet effective, long-term water use efficiency and storage capability.

Blowing soil near Granada, Colorado, in 1936. Instructional Services archived photograph, digitized by Dr. H.F. Schwartz, CSU/BSPM.



The tree-ring reconstructed megadrought of the mid- to late-16th century over much of North America (at left, top) is compared with tree-ring reconstructed drought and wetness during the 20th century (bottom). All reconstructions have been smoothed to highlight decadal variability and represent the PDSI, except in Mexico and western Canada (second column from left, upper time series), which are estimates of precipitation. All reconstructions have been normalized (plotted in standard deviation units) and smoothed to highlight decadal variability. Black shading emphasizes dryness. The time series are placed on the map close to their true geographical position. From D.W. Stahle, et al., 2000, EOS, Vol. 81, Number 12, March 12, 2000.

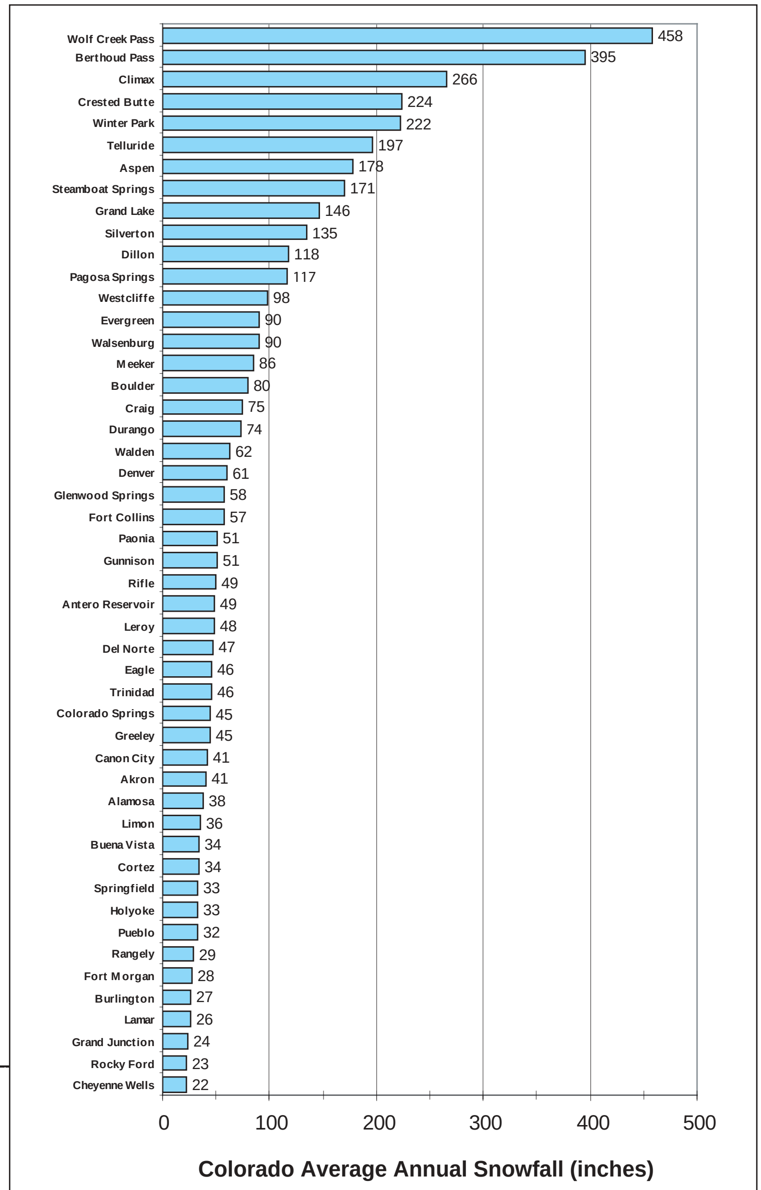
For Teachers *(continued from page 7)*

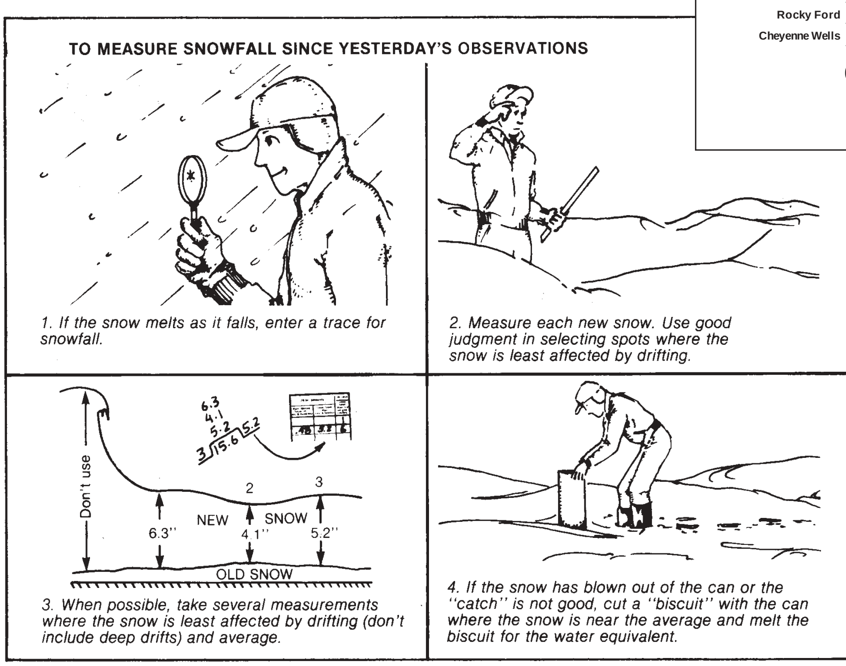
students compute some basic statistics – average, median, range, and any other property of the distribution you like. You could draw or create on the computer histograms of snow accumulation from your set of measurements. There are few limits.

If possible, you should also measure the water content of the snow. That requires a little more work, but it is the water content that in the end is the single most important aspect of snow. Snow is an amazing process that harvests water vapor from the sky and deposits it on the ground so that it can gently melt and soak in even more effectively than rain. In the mountains, the snowpack is our frozen reservoir providing water to most residents of the state and to millions more people downstream who benefit from the waters of the Colorado River, the Platte, the Arkansas, and the Rio Grande. I've run out of time to go into intricate detail on how you can have your kids measure the water content of snow, but I have a funny feeling you can figure that out on your own. It's never quite as easy as it seems, but it is something that every student can do and learn from.

Finally, when you're back in the warmth and comfort of your classroom, consider having your students do some snowfall comparisons. What is the average winter snowfall for your town? What is the snowiest month? How does your snowfall compare to other parts of Colorado and other parts of the country? You can even compare to other parts of the world. With a little homework ahead of time, you can find some websites with snowfall data for many parts of the country to help with this comparison.

Enjoy winter, and enjoy snow. When in doubt, go ahead and act like a kid catching snowflakes on your tongue. You'll feel like a kid again, and your students will think you're pretty neat. If you have questions about snow in Colorado, we'll do our best to answer them. Have a great winter!





1. If the snow melts as it falls, enter a trace for snowfall.

2. Measure each new snow. Use good judgment in selecting spots where the snow is least affected by drifting.

3. When possible, take several measurements where the snow is least affected by drifting (don't include deep drifts) and average.

4. If the snow has blown out of the can or the "catch" is not good, cut a "biscuit" with the can where the snow is near the average and melt the biscuit for the water equivalent.

Courtesy of National Weather Service.

Blizzard *(continued from page 16)*

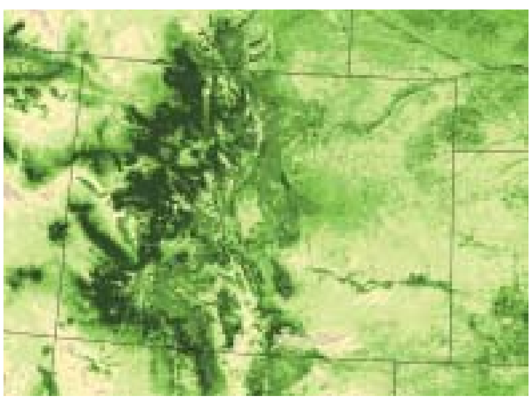
February 1989: Blizzard conditions developed suddenly along I-70 in western Colorado as temperatures plummeted (western Colorado is not accustomed to the extreme rapid changes that are more common east of the mountains). Eagle, normally a dry mountain valley, recorded a quick 16 inches of snowfall and Grand Junction reported 11 inches. World Cup ski events at Vail were cancelled because of extreme winter weather conditions, with subzero temperatures, strong winds, and at least three feet of new snow.

October 24-25, 1997: Perhaps the most severe blizzard to strike eastern Colorado so early in the season, this storm dropped one to three feet of snow in just over 24 hours with winds gusting to 60 miles per hour. The Arkansas Valley was especially hard hit and remained snow covered for much of the winter. Some structures were damaged or collapsed in southeastern Colorado under the weight of large snowdrifts. Several people lost their lives. In the mountains, extremely strong easterly winds developed at mountain-top level during the height of the storm. Millions of trees were blown down in the forest northeast of Steamboat Springs.

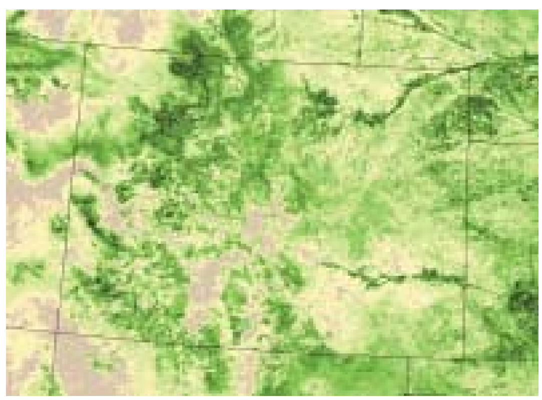
Share Your Story:

As you reflect on some of the storms you've experienced, perhaps you have a story that needs to be shared. If so, submit it in writing to the Colorado Climate Center, and we will be delighted to include it in our historic climate data archives. Stories may be chosen for publication. Photos to accompany your stories will be greatly appreciated.

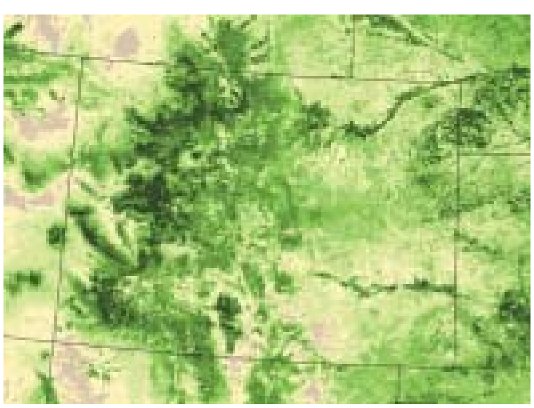
Colorado NDVI Greenness Images



June 2000



August 2000



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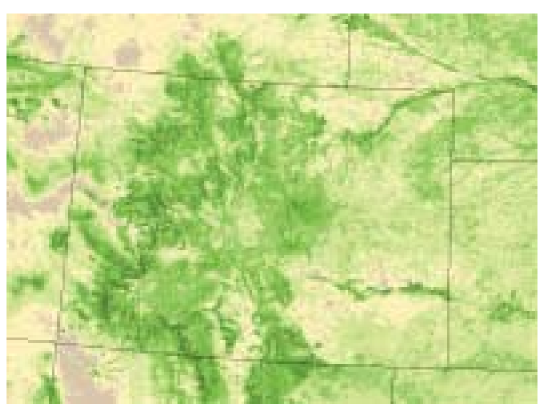


September 2000

Colorado NDVI (Normalized Difference Vegetation Index) greenness satellite images are shown here for June through September 2000. The decreased greenness seen in these images shows the drying up of vegetation or harvesting of crops over this time period.

Images courtesy of U.S. Geological Survey EROS Data Center, Sioux Falls, SD.

Climate Data at Work – Snow Loads

Nolan J. Doesken

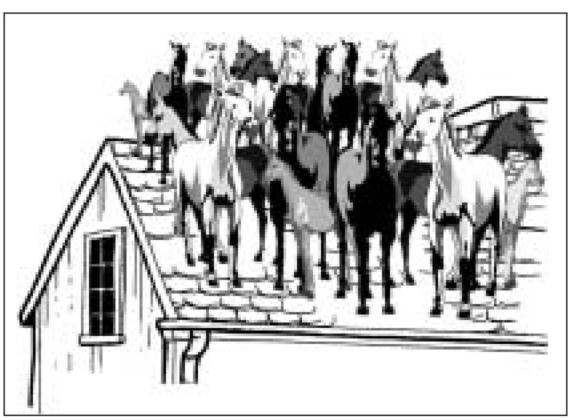
Did you ever drive through Steamboat Springs on a calm, sunny day in late February and wonder why all the young men were standing on rooftops with their shirts off? It wasn't just to impress the young ladies or to get an early tan. They are up there to protect the buildings from the weight of snow.

Have you ever thought about your own roof? When was it built? Who designed it? How strong is it? These are things you usually don't worry about – unless, of course, there are four feet of heavy, wet snow perched up there and your ceiling over your bed is beginning to crack and sag.

Photo taken by Charles Kuster, Leadville, Colorado.

Fortunately our county building officials all across Colorado do think about things like this so we don't have to. Years ago, structural engineers and climatologists put their heads together and developed the concept of "Snow Load." That engineering term simply refers to the forces applied by the weight of snow. These forces must be accounted for as new buildings are designed and older buildings are renovated.

As harmless as it may look, snow that accumulates gradually all winter as it does up in the mountains, or snow that falls in sudden heavy dumps as it sometimes does at lower elevations applies extreme forces on buildings. If they are not adequately designed, roofs can be damaged or even collapse. Through history, there has been disaster after disaster caused by roof failures following seemingly harmless accumulations of snow. One of the most famous collapses was the Knickerbocker Theater in Washington D.C. back in 1922 following a heavy snow. The Civic Center Coliseum in Hartford, Conn., collapsed following a "Nor'easter" on January 18, 1978. Many buildings in the southeast were damaged or destroyed by the powerful snowstorm of March 13, 1993, that was called by many "the storm of the century." Even though we are accustomed to snow here in Colorado, there are still many examples through the years of structural failures resulting from snow. The most memorable storm was the great blizzard of 1913. Building collapses were reported in many cities from Trinidad to Fort Collins after four days of heavy snow, much of it wet, not fluffy. More recently, the roof of one of historic Georgetown's famous old buildings collapsed in May 1969 after a heavy spring storm. A restaurant in Boulder was badly damaged following a surprise 30-inch May snowstorm in 1978. In March 1990, students at Rocky Mountain High School were evacuated from the school when teachers and students noticed ceiling tile bending or falling off as steel trusses bent under the weight of a very wet 17-inch snowfall. As recently as the October 1997 blizzard, buildings in southeastern Colorado were damaged by the weight of snow.



So let's make some calculations. How much does snow weigh? A foot of fresh snow here in Colorado will typically melt down to somewhere between 0.70" and 1.00" of water. Sometimes, the snow is so fluffy that a foot of snow may only contain 0.30" of water or less. However, if that snow is wetter than average, such as our autumn or spring storms, then the water content may be much more. The Fort Collins storm of March 6, 1990, dropped 17 inches of snowfall in just over 24 hours, but at temperatures just above the freezing point and with much of the snow falling in the form of pellets, the snow had a remarkable water content of 3.48" as measured at the official weather station on the campus of Colorado State University. Realizing that a cubic foot of water weights just over 62 pounds, then we can determine that a square foot of a flat roof covered with 17 inches of snow with a water content of 3.48" weights 18.1 pounds. That may not sound like much until you think about how large your roof is. A modest 1,500-square-foot single-story ranch-style house will typically have at least 1,700 square feet of roof surface. Actually, since the roof is sloped, the area will be greater, but it is the equivalent horizontal roof area that we care about. Considering porches and eaves, this area is typically about 10 percent greater than the area of the house itself. Multiply the number of pounds of snow per square foot by the number of horizontal square feet of roof, and you come up with 1,700 square feet x 18.1 pounds per square feet = 30,763 pounds. That's more than 15 tons. That's equivalent to having a dump truck parked up on your roof – or a whole herd of horses for you animal lovers.

The reason the 1913 storm was so bad in Colorado was because of the incredible water content. Not only was this a very deep snow, but also it was wet. The observed water content of the 45.7" of fresh snow reported in Denver December 1-5 was 5.21" as measured by a rooftop precipitation gauge. Gauges notoriously catch less of the water content of the snow than actually fell, so the real content was likely 10 to 20 percent greater. Assuming that the actual water content on the ground as the storm ended on December 6, 1913, was 6 inches, that represents 31.2 pounds per square foot. Even greater amounts were reported over other portions of the Colorado Front Range. If you had that same 1,700-square-foot roof, that adds up to over 53,000 pounds of snow, if that storm were to occur today.

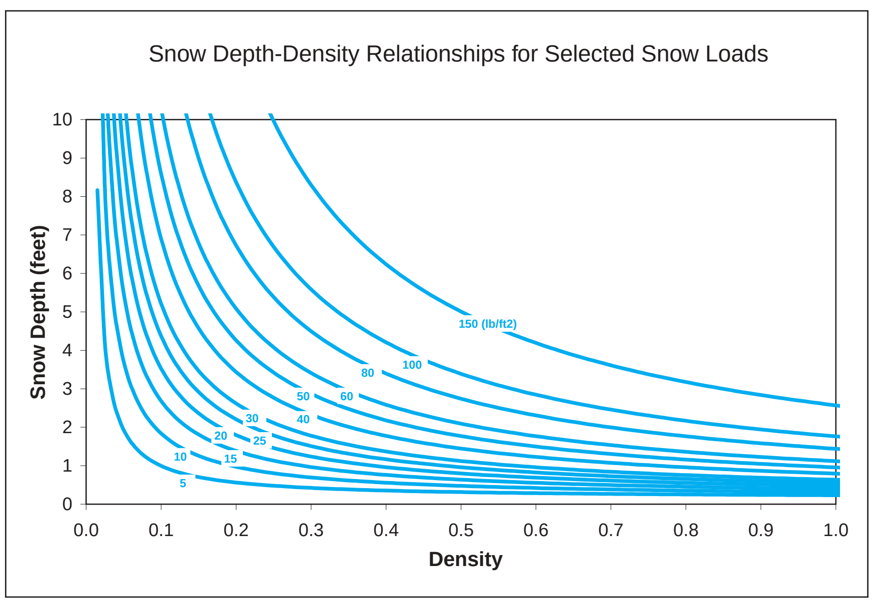
In the mountains we have even a greater challenge. There, the snows may not be as dense when the snow first falls, but with colder temperatures the snow doesn't melt between storms. Rather, it continues to accumulate all winter as shown in the figure below. The snowiest areas in the Colorado high country may accumulate from 20 to 50 inches of snow water equivalent until the snow begins to melt in spring. The greatest accumulations are noted in March, April, and May just before the temperatures warm up. A 50-inch snow water equivalent in the spring snowpack represents 260 pounds per square foot. Now you know why you don't see many flat roofed buildings up in the mountains. Engineers have long known that buildings in high snow accumulation areas must be able to shed snow. Otherwise the cost of construction becomes exorbitant. For modest sloped roofs, like some of the ones you see in Steamboat Springs, it is cheaper to hire a shoveling crew than to renovate older buildings to withstand the weight of the heaviest snow accumulation.

To determine snow loads, it is not good enough just to know the depth of snow. You must also know the snow density (water content per unit volume of snow) or you must measure the total water content by weighing or melting a representative core sample of snow. Much of the fresh snow that falls in Colorado falls at densities between 5 and 10 percent (10 percent means 10 inches of snow would contain 1 inch of water; 5 percent means that 10 inches of snow would contain 0.50 inches of water). The wetter snows may be 10 to 20 percent water. However, as snow ages, compacts, freezes, and thaws, its density increases so that the snowpack just prior to melting may be 25 to 50 percent water. The graph above shows snow loads for various combinations of snow depths and densities.

There is one other thing to think about. Does the snow always accumulate uniformly? Since wind-caused drifting and shading tend to produce very uneven distributions of snow accumulation, structural engineers also have to take that into account. The October 1997 blizzard did not exceed design snow loads, but a few buildings were damaged due to the combination of large drifts and strong winds that applied additional forces. Engineering isn't for everyone, but be thankful that we have people who love the challenge of figuring out all the combinations of environmental forces and how to design and build structures that can handle them.

The next time we have a very heavy snow, look at your roof and be thankful that there are building codes in place that are based on many years of snow data. Your roof is likely designed to withstand a 50 to 100-year snow load. With the many safety factors used by engineers it will likely be around a lot longer than that. So sleep well.

Drug store roof collapsed under weight of snow from March 13, 1993 record snowstorm. Photo by Grant Goodge.



Snow loads in pounds per square feet for combination of snow depth and density. Note: in the real world, the density of snow is not uniform, but this at least gives us something to start with.

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